Final Report to NASA KSC on the Airborne Field Mill Project (ABFM) under NASA Grant NAG10-284

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The following is the Summary of Results Section from the NCAR Final Report on the ABFM project. For information on the project and the basis for these conclusions see the full NCAR FINAL REPORT.

8. SUMMARY OF RESULTS

Three field campaigns were conducted during the Airborne Field Mill Project II (ABFM) to investigate the relationships between electric field intensity, reflectivity and particle microphysics. The June 2000 and May/June 2001 campaigns were very successful in providing many measurements in anvils, convective debris, weak to moderate intensity deep convection and stratiform situations. The February 2001 campaign, conducted during conditions of severe drought in central Florida, provided limited measurements in thick clouds. As a result most of the analysis of ABFM observations have focused on anvils. We have gathered over or near KSC an excellent, unique data set, hitherto unavailable in the scientific community, with 3-dimensional electric field and detailed microphysical measurements in coordination with radar measurements. This data set is valuable for use in developing new Lightning Launch Commit Criteria rules but also for scientific investigations.

The primary results from ABFM II for anvils are as follows:

8.1 Electric Fields and Microphysics

- In regions of anvils with strong electric fields (in large degree also for debris cases), there was a surprising degree of consistency of observed particle concentrations in different size ranges from flight to flight.
- When strong electric fields (> 10 kV/m) occurred, the particle concentrations in all size ranges from tens of microns to several millimeters were high, but higher particle concentrations did not necessarily indicate regions of strong electric field.
- The smaller ice particles in the anvils (<50 μm) are primarily spherical thereby suggesting frozen cloud droplets. Almost all particles >100 μm are irregular with

little evidence of riming except near storm cores. Pristine ice crystals were observed infrequently. Most particles > 500 μm have the appearance of aggregates. Long chains of aggregates were frequently seen suggesting enhancement of aggregation by the strong electric fields. Additional research could be done on this topic using this unique data set.

- Scatter plots of the anvil data set showed an unexpected, complex relationship between electric field and particle concentrations for all size ranges. For electric fields >3 kV/m up to the maximum of ~45 kV/m there is not much change of concentration with increasing field, but for Emag < 3 kV/m there are wide ranges of concentration for relatively small changes of field and a knee or inflection point in the plots.
- At this time, we have no explanation for the change in character of the electric field and particle concentration relationship near 3 kV/m.
- There was no evidence of supercooled liquid water being present in the anvils. This suggests that active electrification via the non-inductive charging mechanism is probably not occurring to any significant degree in these anvils.
- However, in several cases we observed the transition of anvils into a secondary development, a stratiform-like layer. During this secondary development electric fields persisted for extended periods of time and perhaps even intensified. Reflectivity persisted for long periods and sometimes increased, especially near the 0C level but also aloft. (See Dye et al., (ICCP2004 preprint) for the example of the June 4, 2001 case and J. Willett's Final Report on the ABFM Web Report page). This topic warrants further investigation.
- Even though this stratiform-like development occurred in some anvils, Column Averaged or Volume Integral reflectivity continued to provide good guidance on the presence of strong electric fields. The behavior of the Emag vs. reflectivity scatter plots was the same when these secondary development regions were included as well as when they were not.

8.2 Reflectivity and Microphysics

- The relationship between reflectivity (of a 3 km cube near the aircraft) and particle concentration was found to be consistent with a power law in all size ranges from the smallest to the largest, but with more variation for the small and intermediate-sized particles than for the particles > 1mm.
- The particles > 3mm, our largest size category, exhibited the best correlation with reflectivity, as expected.
- The scatter plots of reflectivity versus particle concentration did not exhibit a complex behavior, unlike the scatter plots of electric field versus particle concentration.
- Measurements near anvil edge clearly showed that particles extend out to or beyond the 0 dBZ radar contour and well beyond the 10 dBZ radar contour. As a result of ABFM observations the LAP changed the definition of "anvil edge" in the LLCC rules from +10 dBZ to 0 dBZ.

8.3 Electric Field Reflectivity

- Strong electric fields were found to be associated with regions of higher reflectivity (>~5 to 10 dBZ) above the freezing level (assumed to be >= 5 km MSL), but higher reflectivity did not necessarily indicate regions of strong electric field.
- The change in behavior of the character of the electric field and particle relationship near 3 kV/m carries over to and impacts the relationship of electric field with reflectivity and with electrical decay times.
- Reflectivity at the aircraft location or in the 1x1 km column above the aircraft measured by the 74C and NEXRAD radars at anvil altitudes over KSC is not a suitable parameter for comparing to electric field strength. because of scan gaps between antenna sweeps of both radars. Additionally, strong temperature gradients can at times cause significant refraction of the radar beam.
- A reflectivity parameter, the 11x11 or 21x21 Column average, was developed to minimize the effects of scan gaps and also to detect possible sources of strong electric fields in the large volume near but not at the aircraft location.

8.4 Electrical Decay Time Scale, Microphysics, Reflectivity and Electric Field

- A simple model was developed to estimate the decay of electric field in the ABFM anvils based upon the observed particle size distributions. (Willett, Final Report, 2003). Because the model assumes constant microphysics during the field decay, the model times are considered upper limits.
- An electrical decay time scale, ETmScl (or τ_E in Willett's reports) is calculated for each 30 s average of aircraft data in anvil to estimate from the model the time for the electric field to decay from 50 to 0 kV/m. In the high field limit, ie. for fields approximately > 2 kV/m, the decay is linear.
- The particle cross sectional area, particularly in the size range 0.2 to 2 mm, largely controls the calculated electric field decay time scales for anvils in the model.
- The optical extinction coefficient (as well as electrical decay time) is also weighted toward mid-sized particles 200 to 2000 μm. See Willett (2003b) on Optical Extinction Coefficient.).
- The observed particle size distributions yield calculated electric field decay time scales ranged from 3 hours near the core of active storms to only a few minutes near the edge of anvils.
- Plots of the electrical decay time scale versus electric field show a large change in the plots near 3 kV/m similar to those of electric field versus particle concentration. This is a result of the change in character of the electric field and particle concentration relationship.
- Comparisons for case study days of electric field decay time scale from the model with observed decay times were generally consistent, but only one ABFM anvil case permitted a meaningful comparison.
- Neither reflectivity nor electrical time scale are a suitable proxy for electric field.

8.5 Consideration of Possible Radar Variables for an LLCC Rule

- Scatter plots of the 11x11 or 21x21 Column average versus the magnitude of the electric field, Emag have been useful for considering a possible radar based LLCC rule. Such plots have the behavior that for reflectivity less than some threshold value, no points with moderate or strong electric fields (> 3 kV/m) were observed.

- The 11x11 column is preferable to the 21x21 column for the purpose of calculating either average or another radar variable for use in an LLCC.
- The arithmetic average of dBZ values is preferable to a geometric average (in which dBZ is converted to Ze, averaged, and then converted back to dBZ), because the geometric average gives most weight to the very largest reflectivity. Similarly this is true for the maximum reflectivity.
- The11x11Volume Integral (the product of the 11x11Column average and the average 11x11Thickness) was found to have a smaller False Alarm Rate than the 11x11Column average. The volume integral was also less sensitive to the reflectivity cutoff being used, -10 or 0 dBZ and therefore more robust.
- At this time, the 11x11Volume Integral appears to be the most promising radar variable for use in an LLCC rule.
- If the primary consideration is to prevent statistical bias, a cutoff threshold for the radar measurements of –10 dBZ is preferable to a 0 dBZ cutoff for use in calculating column average or anvil thickness.
- There was considerable debate about whether a cutoff of –10 dBZ or a cutoff of 0 dBZ was preferable for use in an LLCC. This is a topic for further investigation and discussion.
- An examination of the entire ABFM data set (not just anvils) showed that electric field falls off rapidly from cloud edge. By 9 km distance from the cloud edge electric fields are <1.5 kV/m.
- For debris clouds, the scatter plots of reflectivity parameters versus electric field were very similar in nature to the scatter plots for anvils. A radar based LLCC for debris clouds might be very similar to the one presently being developed for anvils.